

Active deformation in the Pamir – Tian Shan collision zone, NW China

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Crustal shortening caused by the Cenozoic convergence of India and Eurasia extends far north of the Indo-Asian suture and is accommodated by intracontinental mountain ranges. Northwest of the Himalaya, Cenozoic convergence led to the northward propagation of the Pamir, the closing of the seaway between the Pamir and the Tian Shan and eventually the collision of the two oppositely verging orogens [1]. The Pamir and Tian Shan currently accommodate 20–25 mm/y of shortening and are among the fastest deforming mountain ranges on Earth [2]. 8–12 mm/y of convergence are taken up across the boundary between the two orogens alone [2]. Shortening across the boundary in the center of the collision zone has been mostly accommodated on the Main Pamir Thrust (MPT) [3]. At the northeastern edge of the Pamir in westernmost China, however, deformation has stepped away from the mountain fronts into the foreland and is accommodated by a series of thrusts, thrust-related folds, and detachment folds [4,5,6] (Fig 1). Studies of Quaternary and Holocene deformation reveal 5–7 mm/y of shortening along the Pamir Frontal Thrust (PFT) [6] and up to 5 mm/y of shortening across the Atushi and Kashi folds [4,5].

We present a new dataset of relative decadal deformation from Interferometric Synthetic Aperture Radar (InSAR) time series analysis using a combination of small-baseline and persistent-scatterer techniques using the StaMPS/MTI package [7,8] (Fig 2). Our data are centered on the foreland of the Pamir - Tian Shan – Tarim basin triple junction in westernmost China around the city of Kashgar and show no significant residual topographic phase correlation. The result reveals that decadal deformation is concentrated on a few select structures in the foreland of the Pamir and Tian Shan. No modern deformation along the Main Pamir Thrust (MPT) can be detected which is consistent with published thermochronology data [9]. The highest relative line-of-sight (LOS) displacements of 3–4 mm/y are observed on the Pamir Frontal Thrust and related two anticlines as well as the Kashi detachment anticline.

Meaningful comparison of LOS displacement and Quaternary fault slip rates is difficult, given the high uncertainties on the dip of the PFT, on the Quaternary deformation rates, and on the InSAR displacements. Within error, the decadal rates agree with published millennial time-scale estimates. Similarly, the pattern of deformation along the PFT matches well with previous studies. Modeling suggests that the PFT is segmented into creeping and locked portions of 10 to 20 km length. Clear mismatches between short-term and longer term rates exist on the two young detachment anticlines in the Tian Shan foreland. The Atushi fold which has been active for the last 2 Ma [5] shows no significant activity in the last decade which might suggest that deformation has mostly stepped south to the Kashi fold. Moreover, on the eastern part of the Kashi fold, the

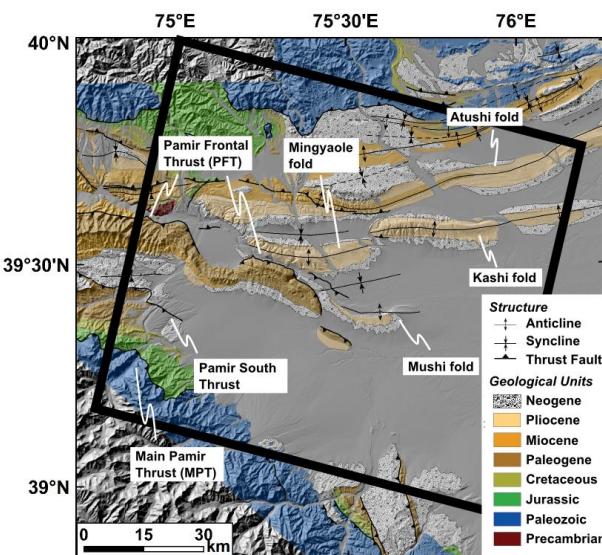


Figure 1: Geologic map of the study area. The black rectangle outlines the coverage of the InSAR data

InSAR LOS displacement is significantly higher than the average rate since initiation of the folding 0.8 Ma ago [4]. Uplift on the eastern portion seems to have accelerated to the modern rate. Data further east are necessary to substantiate this analysis.

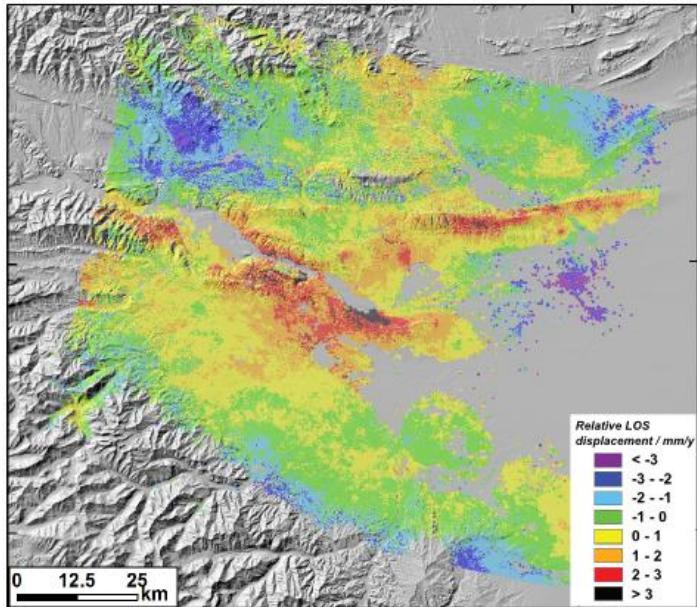


Figure 2: Mean yearly LOS displacements from 2004 - 2010.

Tian Shan and Pamir can only partly be explained by the dry climate in the Tarim basin and instead indicate relatively steep streams due to rapid uplift in the foreland that drives an increase in the normalized steepness index. Thirdly, heads of alluvial fans start to propagate back into the mountains. This observation is clearest in the Tian Shan because of the earlier cessation of activity. Whereas stream morphology in the study area reflects the tectonics on a scale of 100s of km, the hydrologic network does not respond consistently to the more detailed variation of uplift rates on the scale of 10s of km. Stream profiles of major streams across active structures only change detectably where strong lithologies are exposed in the core of the active uplift. Steepness indices of small streams draining the active and inactive structures are very similar. Finally, other commonly used topographic metrics such as elevation and km-scale relief do not correlate well with the pattern of activity. We interpret that the variation of these metrics is strongly controlled by the age of the structures and the differential erodibility of the rock types rather than the uplift rate. We suggest that despite rapid deformation rates, the 1-2 Myr of activity were not enough for the structure to reach a “steady state” in which topographic metrics reflect the active uplift pattern.

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We combine the InSAR results with topographic data, stream profiles, and normalized steepness indices [10] to show that common topographic metrics seem to confirm the broad observations from decadal and Quaternary tectonic studies, but fail to capture the detailed pattern of uplift. Three main observations suggest that stream morphologies reflect the cessation of activity on the frontal thrusts of the Pamir and Tian Shan and propagation of active tectonics into the foreland. Firstly, no significant change in the stream profiles or normalized steepness indices across the front of the high mountains can be detected in most rivers. Significant decrease of the slope occurs downstream of the alluvial fans. Secondly, straight or slightly convex stream profiles of rivers draining the

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